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ABSTRACT

The taxonomy presented in this paper lends structure to the range of tasks or problems possible within an interactive graphical medium. Some 70 items from a testing project were the basis for forming the categories described in the taxonomy. Items were drawn from science and technology domains. The categorical scheme was refined iteratively by two raters until it was able to accommodate all items. The framework is intended to have utility in the design of problems cast within an interactive graphical medium. The following item types are included: (1) point to image element; (2) evaluate image; (3) show direction/path; (4) show height, extent, or boundaries; (5) assemble elements; 6) indicate categorical, ordinal, or functional relationships; and (7) indicate continuous relationships. (Contains one table and eight references.) (Author/SLD)

A Taxonomy of Methods for Demonstration of Proficiency in a Figural Medium

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Summary

The taxonomy presented in this paper lends structure to the range of tasks or problems possible within an interactive graphical medium. Some 70 items from a testing project were the basis for forming the categories described in the taxonomy. Items were drawn from science and technology domains. The categorical scheme was refined iteratively by two raters until it was able to accommodate all items. The framework is intended to have utility in the design of problems cast within an interactive graphical medium.

An Initial Taxonomy of Methods for Demonstration of Proficiency in a Figural Medium

Computer-based testing and learning environments afford the opportunity for users to interact with knowledge representations that can take a variety of forms. Among these, interactive graphical representations are noteworthy because they are absent from the repertoire of text-based materials. Graphical depictions are important because they bear resemblance to the type of dynamic analogical representations called mental models (Gentner & Gentner, 1983; Johnson-Laird, 1983). One expression of testing that relies on graphical representations is the figural response item format. Figural response items are constrained to be tasks in which (a) an examinee demonstrates proficiency by adding to, arranging, or otherwise modifying figural material, and in which (b) the response is mentally constructed, not chosen from a list.

Figural response items have been developed for paper-and-pencil assessment in science (Martinez, 1991), as well as computer-delivered assessment in architecture, cell/molecular biology, and engineering (Martinez & Katz, 1996). In these projects, item development proceeded in an exploratory and creative fashion, often by recruiting domain experts to construct tasks compatible with constraints (a) and (b). One persistent problem, however, was understanding the *range* and *kinds* of tasks which can be set within a figural medium, as well as the cognitive demands of those tasks. The need for a taxonomy of item types led to the scheme proposed in Table 1.

Table 1 About Here

Each of approximately 70 items was clustered provisionally with similar items. When no existing category could accommodate an item, a new category was created; ambiguities led to further definition of item types. This process proceeded iteratively, until all items could be placed into groups unambiguously. On the basis of iterative conceptual refinement, Table 1 was revised to its present form. The resulting item types are defined to be distinguishable on the basis of (a) the nature of the task, (b) the given information in the problem, and (c) the cognitive processes used to construct a correct response. These features correspond to columns in Table 1. The last column lists non-exhaustive criteria that could be used to score responses.

Each item type is now described in turn.

TYPE I: POINT TO IMAGE ELEMENT

The first item type involves "pointing to" named structures. In its most basic form, Type I is essentially a multiple-choice question but with large numbers of response options. For example, if a user is presented with an unlabeled map of the world, one could ask, "Where is Australia?" A response is indicated by moving a pointer to a specific area and marking it. Asking, "Where is Tongatapu?" makes the question more difficult, and if international boundary lines are removed, a mental construction of a response is required. Likewise, in viewing X-rays or bubble chamber tracks, the specialist can perceptually isolate a named element from a complex image. Perceptual isolation in a complex visual field is an important aspect of expertise in some fields (deGroot, 1965)—and is not assessed well by traditional tests where potential responses must be marked clearly, pre-empting perceptual isolation on the part of the examinee.

TYPE II: EVALUATE IMAGE

Type II involves identifying an element of a figure with its name or symbol, detecting a structural error, or computing a value or attribute. For example, one could present architects with truss diagrams and ask them to label each truss member as being in tension, compression, or having no net internal force. This task might be seen as a set of multiple-choice questions, since only three options exist for each truss member, but in fact the problem is likely to invite complex reasoning because evaluating the forces within a truss member entails consideration of the truss as a whole, and requires inferences about effects that propagate within the structure. The evaluation of an image might be combined with "pointing to" image elements (Type I). For example, a technician might be asked to evaluate an X-ray film by pointing to anomalies. In this case, evaluation is combined with the tasks of perceptually sorting and interpreting the pieces of the complex image.

TYPE III: SHOW DIRECTION/PATH

This category asks an examinee to show the directions of motion (linear or curvilinear), vector quantities, or paths. The ability to indicate directions and paths are important aspects of understanding in many scientific, technical, and vocational fields. This mode allows an examinee to demonstrate, for example, knowledge of kinematics, including naive conceptions (Clement, 1982). Paths of fluids, light, and electric current could be shown as well. A complex path could also be indicated. For example, an examinee might trace a path on a city map to show the most direct route from one location to another.

TYPE IV: SHOW HEIGHT, EXTENT, OR BOUNDARIES

Type IV items call for an indication of unidimensional extent or spatial extent. Some items asked examinees to indicate the height of a mercury column in a thermometer or of a liquid in a test tube. Architecture items involved drawing property lines while others required demarcation of building sections that would move independently during an earthquake. To some degree, all Type IV items call for judging "how much." The item type does not involve pointing to a pre-existing structure, but marking an image to indicate extent.

TYPE V: ASSEMBLE ELEMENTS

Type V items are arguably best suited to the capabilities of a computer-based figural format. Within the scope of this item type is a wide range of possible items that would be impossible to duplicate on paper. In architecture, some of the items involved constructing a structure from a "kit of parts." In engineering also, a circuit can be assembled from components. Other architecture items involved placement of pre-drawn buildings and vegetation on a site to satisfy constraints that are either explicit or assumed from convention. Assembly usually involves rotation and movement of existing elements, but new structures could also be created and added to an assembly. Some architecture items, for example, asked for the placement of a water vapor barrier in a building cross-section. The vapor barrier would be drawn using a line-drawing tool.

TYPE VI: INDICATE CATEGORICAL, ORDINAL, OR FUNCTIONAL RELATIONSHIPS

These items ask examinees to depict relationships among discrete elements. Nominal (categorical) relationships can be indicated by separating elements (pictures or words) into lists or cells of a matrix. Ordinality could likewise be shown by arranging elements within pre-set or user-specified dimensions. For example, names or shapes of countries could be placed in a two-dimensional grid labeled *per capita GDP* and *birth rate*. If *exact* placement on these dimensions were desired, rather than merely *ordered* placement, that requirement could be specified in instructions and the response scored accordingly. Functional relationships could also be specified by using flow charts, hierarchies, semantic nets, and concept maps (Lambiotte, Dansereau, Cross, & Reynolds, 1989).

TYPE VII: INDICATE CONTINUOUS RELATIONSHIPS

Finally, continuous relationships can be indicated using line graphs. One science item, for example, asked the learner to draw the relationship between the temperature of water and heat input as the water changes phase from ice to liquid to steam. Continuous relationships can be scored according to a precise ideal response (with specified tolerances for error) or according to their general form. Many core concepts in science and technology can be depicted as relationships between continuous variables, including predator-prey relationships, supply and demand curves, and radioactive decay.

Discussion

The scheme described in this paper is not a definitive catalogue of task types possible within a graphical environment. It is, however, a starting point for describing existing figure-based tasks and test items. It is also a framework for item construction and for invention of new tasks involving the manipulation of graphics. The importance of the scheme goes beyond the context of computer-assisted testing to virtually any situation where a computer is used to promote learning.

A few generalizations can be made from the typology. First, the range of figural response items includes types that are especially suited to computer-based environments and difficult or impossible to imitate using the multiple-choice or paper-based formats. Type V (assembly of elements) problems are the best example. If these were reconfigured to be multiple-choice questions or forced to expression on paper, their cognitive requirements would change drastically. Similarly, for Type I (point to image element) items, making structures explicit for a multiple-choice version would circumvent the very perceptual isolation of elements desired from examinees. Multiple-choice forms of Types VI (indicate categorical, ordinal, or functional relationships) and VII (indicate continuous relationships) would present the work of indicating relationships in complete form, leaving the user the unexciting task of selecting a correct arrangement from a small set of mostly-incorrect graphics.

The focus here has been the demonstration of proficiency in a two-dimensional medium. However, all of the task types described could be posed in three dimensions. In some cases, such as *assembly*, a third dimension would lend greater authenticity to many problems. In other cases, such as graph construction, an extra dimension would add to the complexity of the representation and presumably to the sophistication of the knowledge and reasoning required by the user to respond correctly. But even a two-dimensional graphical medium can expand the repertoire of item types and the kind of cognitive assessments elicited by assessments. On the other hand, demonstrations of proficiency in a two-dimensional graphical medium might merely provide examinees with an alternative means to demonstrate their understanding, but showing it *another way* can sometimes be the best evidence that one truly understands (Sigel, 1991).

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Table 1
Taxonomy of Items for the Figural Response Format

Type	Task	Givens	Cognitive Processes	Scoring Criteria
I	Point to image element	Name of element and complex image	Recognize/recall image; possibly isolate image element perceptually	Location within response field
II	Evaluate image	Image	Retrieve name, symbol; compute value/attribute; detect error	Location within response field; selection/construction of evaluation; etc.
III	Show direction/path of motion	Initial trajectory; vectors; path criteria	Determine direction or path	Match with ideal direction or path
IV	Show height, extent, or boundaries	Referenced background (e.g., scale)	Determine how much, where, and in what position	Location within response field or position relative to other marks
V	Assemble elements; possibly create elements	Element set and/or a partial structure	Determine structure	Location, orientation,
VI	Indicate categorical, ordinal, or functional relationships	Concepts and group names, dimension axes, matrix, or links	Determine categorical identities, orders, or relationships	Location; relation
VII	Indicate continuous relationships	Data or concepts and dimension axes	Determine continuous relationships linear non-linear	Location, orientation, straight or relation free-form

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